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TECHNICAL INFORMATION PAMPHLET ON USE OF FIBROUS CONCRETE

ARMY CONSTRUCTION ENGINEERING RESEARCH LABORATORY

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TECHNICAL INFORMATION PAMPHLET ON USE OF FIBROUS CONCRETE

(Applicability of Fibrous Concrete for Military Facilities)

by

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May 1973

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This report discusses various guidelines for the use of fibrous (steel fibers) concrete by field personnel. Included are definitions of the nature of fibrous concrete, reasons for using it, properties and characteristics of the material, types and sources of steel fibers, and concrete mix design procedures.

The report specifically discusses methods for handling and batching steel fibers, concrete quality control, and concrete placing, finishing, and curing. Explanations of promising applications, costs, and sources of assistance are provided.

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FOREWORD

This report was prepared for the Facilities Engineering Division, Directorate of Military Construction, Office of the Chief of Engineers (OCE), U.S. Army Corps of Engineers, Washington, DC. Development of the report was funded under Research, Development, Test, and Evaluation Program 6.47.17A, Project A4664717D895, Task 23, "Military Airfield Facilities," Work Unit 003, "Applicability of Fibrous Concrete for Military Facilities." The OCE Technical Monitor for this work unit and coordinator for the report was Mr. Leo Price.

The report was prepared by the Materials Division, Construction Engineering Research Laboratory (CERL), U.S. Army Corps of Engineers, Champaign, Illinois. CERL personnel directly concerned were Dr. G.R. Williamson, Visiting Professor on a summer academic appointment from Youngstown State University, Youngstown, Ohio, and Mr. B.H. Gray, principal investigator for the work unit. Mr. E.A. Lotz was Chief of the Materials Division. Col. R.W. Reisacher and Dr. L.R. Shaffer were Director and Deputy Director, respectively, of CERL.

TECHNICAL INFORMATION PAMPHLET ON USE OF FIBROUS CONCRETE

1 INTRODUCTION

Definition. Fibrous concrete is conventional concrete with randomly dispersed fibers of short length and small cross-sectional area. Materials used as fibers include steel, glass, asbestos, nylon, polypropylene, and other synthetic and natural materials. Because fibrous concrete made with steel fibers has wider application and overall superior properties to that made with other materials, only steel fibers will be discussed in this pamphlet.

The primary reason for using steel fibers in concrete is to increase the flexural strength and the ductility of the concrete. However, the presence of randomly dispersed steel fibers in concrete also improves its abrasion resistance, resistance to thermal shock, impact resistance, freeze/thaw durability, shear strength, and flexural fatigue endurance limit.

Concept. The idea of incorporating metallic and nonmetallic materials in mortar and concrete to improve or alter the characteristics of the basic material is not new. However, it was only in the early 1960's that a theoretical understanding of the response mechanism of the fibers was introduced. Currently there are two theories advanced to predict the response of fibrous concrete. One is based upon the theory of fracture mechanics as applied to concrete, the other is basically a composite materials approach. Although the comparative validity of the two theories has yet to be resolved, the controversy has generated considerable experimental and developmental work over the past decade.

Properties and Characteristics. The use of steel fibers in a properly proportioned concrete or mortar mix can be expected to result in considerable improvement in the basic properties and characteristics of plain concrete. The properties and the percent of improvement over plain concrete are shown in Table 1, while the advantages resulting from these improved properties are listed in Table 2. The advantages as listed in Table 1 have been verified by laboratory and field investigations for a fibrous concrete containing 2% by volume of steel fiber and can be included in the expected overall response of the material. Design criteria for predicting the strengths and other parameters given in Table 1 have yet to be developed. However, procedures for designing fibrous concrete pavement slabs and overlays have been developed by CERL. These procedures utilize the current Corps of Engineers design procedures with appropriate modifications to account for the higher strengths of fibrous concrete. CERL can provide assistance for the design of slabs and overlays on an individualized basis.

Types and Sources of Steel Fibers. Three types of steel fibers are currently in use: a flat fiber of rectangular cross-section, a round fiber, and a round fiber with evenly spaced flat sections. Fibers with different lengths, cross-sectional areas, and shapes have been tested and are available. In selecting fibers, length-

Table 1
Properties of Fibrous Concrete

Property	Percent Increase Over Plain Concrete
First Crack Flexural Strength	50
Ultimate Modulus of Rupture Strength	100
Ultimate Compressive Strength	15
Ultimate Shear Strength	75
Flexural Fatigue Endurance Limit	225
Impact Resistance	325
Sandblast Abrasion Resistance Index	200
Heat Spalling Resistance Index	300
Freeze/thaw Durability Index	200

Table 2
General Advantages of Fibrous Concrete

Much greater resistance to cracking.
Improved fatigue characteristics.
Far superior resistance to thermal shock.
Significantly thinner sections for a given design.
Elimination or reduction of other types of reinforcing materials.
Increased production rate with thinner sections.
Less maintenance and longer life.
Isotropic properties.

diameter ratio should be kept under 75, or else mixing problems will occur. At this writing, the U.S. Steel Corporation, the National-Standard Company, and the Atlantic Wire Company are the main quantity suppliers of fibers. Since bulk handling facilities have yet to be developed, the fibers are presently being shipped in 40 to 100 lb cardboard boxes to permit manual handling. The three types of fibers proven to be best suited for fibrous concrete are:

Flat Fiber. The dimensions of the most commonly used flat fiber are 0.010 × 0.022 × 1.0 in. This cross-sectional area is approximately equivalent to a fiber 0.016 in. in diameter. This fiber is a product of the U.S. Steel Corporation and is manufactured from low carbon steel plate 0.010 in. thick which has been slit into strips 1.0 in. wide. These strips are then chopped into fibers of the final dimension. The trade name for this fiber is Fibercon, and it is the only fiber available from U.S. Steel on a production basis. Fibers may be obtained by contacting the New Product Development Office, U.S. Steel Corporation, 600 Grant Street, Pittsburgh, Pennsylvania 15230.

Round Fiber. The most widely used round fiber is 0.016 in. ϕ × 1.0 in., which is produced by chopping drawn wire. These fibers can be obtained from the National-Standard Company, 8th and Howard Street, Niles, Michigan 49120 and the Atlantic Wire Company, 1 Church Street, Banford, Connecticut 06405.

Round Fiber With Evenly Spaced Flat Sections. The most commonly used fiber of this type is 0.016 in. ϕ with 0.010 × 0.020 in. flat sections and is 0.75 in. long. The trade name for this fiber is Duoform, and it is manufactured by the National-Standard Company. The various types of steel fibers mentioned above are shown in Figure 1.

Several patents have been issued in the United States encompassing fibrous concrete. However, because the material was originally developed with National Science Foundation funds, the federal government has no patent responsibilities; therefore, unlimited use by the government is permitted. For non-government users, the right to use metallic fibers in concrete is usually automatic with the purchase of fibers.

Typical Mix Design and Design Procedures. In order to obtain a good quality fibrous concrete, an understanding of the interaction of the various constituents is necessary. The addition of fibers to fresh concrete tends to reduce the workability of the mix. The long narrow shape of the fibers promotes interlocking, and the large surface area promotes drying of the mix by the adsorption of free water that would ordinarily be used to produce workability. This problem is easily overcome by designing richer mixes with higher percentages of fine material. The average fibrous concrete mix will contain six to ten bags of cement per cubic yard with 3/8 in. maximum-size coarse aggregate. Aggregate sizes to 1 1/2 in. have been used successfully, although the larger aggregates will reduce the workability of the mix. There is some evidence that the larger aggregates lessen the effectiveness of the fibers. The better the quality of aggregate, the larger the maximum size and the greater the percentage of coarse aggregate that may be used. The fine-coarse aggregate ratio may vary from 3:1 to 1:1, with a 3:2 ratio preferred. A typical fibrous concrete mix design is given in Table 3, together with the concrete properties produced by this design.

Recent work has indicated that a reduced cement content can be achieved by the use of fly ash. Workability is improved without adversely affecting the flexural and compressive strengths. However, the effect of the fly ash upon the other properties of fibrous concrete has not been completely determined. For this reason, fly ash is recommended only for pavement applications or any similar application where flexural strength is the prime consideration. In areas where fly ash is readily available, some savings in the overall cost of fibrous concrete can be expected, since the cost of

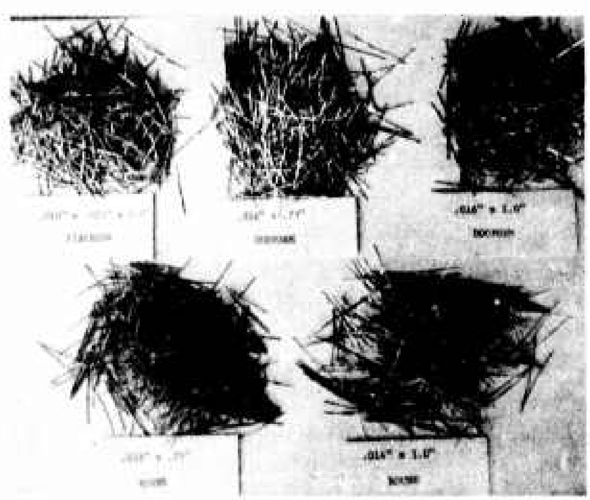

Figure 1. Various types of steel fibers.

Table 3
Fibrous Concrete Mix Design and Strength Properties

Mix Design	
Cement Factor – Type I (94#/bag)	9 bags/cu yd
Water-Cement Ratio	0.46 by wt
Fine-Coarse Aggregate Ratio	3:1
Maximum-Size Coarse Aggregate	3/8 in.
Fiber Content (0.010" × 0.022" × 1.0")	2% by volume
Air Content – Measure	6%
Slump – Measure	3 1/2 in.
Strength Properties	
Test Age	28 days
Flexural Strength (6" × 6" × 21" beam/18" span)	1140 psi
Modulus of Elasticity, E_f, Flexure	5.28×10^6 psi
Compressive Strength (6" ϕ × 12" cylinder)	6960 psi
Tensile Strength (6" ϕ × 12" cylinder)	870 psi

Table 4
Fly Ash Fibrous Concrete Mix Design and Strength Properties

Mix Design		
Cement (94#/bag)	5.32 bags/cu yd	
Fly Ash (75#/bag)	3.0 bags/cu yd	
Water-Cement Ratio	0.54 by wt	
Fine-Coarse Aggregate Ratio	1:1	
Maximum-Size Coarse Aggregate	3/8 in.	
Fiber Content (0.010" × 0.022" × 1.0")	1.5% by volume	
Air Entraining Agent*	per manufacturer's recom.	
Water Reducing Agent*	per manufacturer's recom.	
Slump – Measure	4 in.	
Strength Properties		
Test Age	28 days	90 days
Flexural Strength** (3" × 4" × 14" beam)	1035 psi	1600 psi
Compressive Strength (6" ϕ × 12" cylinder)	5925 psi	5935 psi

* Based on cement content only.
** There is strong indication that the flexural strength rate of development is slower than the compressive strength rate.

fly ash is usually below that of cement. As with any mix using fly ash, the fly ash is used in place of a specified volume amount of cement. In addition to the potential savings, the use of fly ash retards the set, thereby aiding in placing and finishing, provides a mix of high paste content with a lower cement factor, and reduces the required water content while maintaining strength and workability. A fly ash mix design currently being used is given in Table 4. The use of fly ash cement, ASTM C595-67T, has not been investigated, therefore no recommendation for the use of this material can be made.

The recommended procedure for designing a fibrous concrete mix is similar to that used for conventional concrete design. A mix based upon previous experience, such as that in Table 3, is used as a basis for a trial mix. As yet there are no proven methods for proportioning fibers to achieve specified strengths. A number of trial mixes may be required, with the concrete constituents and the fiber content being varied on the basis of judgment. The trial mixes need be only one or two cubic feet with careful attention being given to workability. For example, if the design of a fibrous concrete pavement required a flexural strength of 1100

psi, several trial batches using the job site materials would be made with different percentages of fiber, fine-coarse aggregate ratio, and maximum-size coarse aggregate. Beam and cylinder test specimens would be fabricated and moist-cured for a specified age such as 7, 28, or 90 days. At a selected age the flexural, compressive, and tensile splitting strength of the various mixes would be determined. The mix that contains the lowest percentage of fiber with the largest amount and maximum-size coarse aggregate, and which maintained workability and strength would be the most acceptable mix. Experience with fibrous concrete helps to keep the number of trial mixes to a minimum. Once the mix design has been selected, a full field batch should be processed in the job-site mixing equipment, using materials that will be used for the project, prior to the actual start of construction. Workability and ease of discharge are the prime considerations for the fibrous concrete.

Table 5 can be used to proportion trial batches. Listed are the limits of the various consituents as well as the recommended trial amounts.

2 BATCHING, PLACING, AND FINISHING

General. The same quality control used to produce sound, durable conventional concrete applies also to fibrous concrete. The aggregates must be sound, the water potable, and the mixing thorough. Additives may be used to entrain air, accelerate or retard setting, improve workability, improve placing and finishing characteristics, lower the water-cement ratio, and increase durability. The general methods for improving the characteristics and properties of fibrous concrete have been reproportioning of materials by additions of cement or fine aggregate or by fly ash replacement, placing at a slower rate, and compacting by vibration.

Batching. During batching fibers tend to nest together and form little fiber balls several inches in diameter as shown in Figure 2. Major factors that contribute to fiber balling are: the length to diameter ratio of the fiber, called the aspect ratio; the amount of fibers in the mix by volume percentage; and the batching procedure. Keeping the aspect ratio below 75, the volume percentage under 2.5% and, using the recommended batching method will inhibit the formation of the fiber balls.

For small batches, such as those used for trial mixes, the fiber can be pre-blended with the fine and coarse aggregate outside the mixer, followed by the usual mixing procedure. One method for mixing small batches is to weigh out the aggregates and fibers, and then place alternate layers of aggregate and fibers in a receptacle. This mixture is then placed in the mixer along with the cement and water, and mixing is conducted as for ordinary concrete. By exercising extreme care, it is also possible to add the fibers by slowly sprinkling the fibers into the rotating drum after the concrete has been thoroughly mixed. Any method that produces uniform dispersion of the fibers is satisfactory.

Table 5
Proportioning Trial Batches for Steel Fibers

Material	Range	Recommended First Trial
Cement (94#/bag)	5–10	5-1/3 bags/cu yd
Fly Ash (75#/bag)	0–3	3 bags/cu yd
Water-Cement Ratio	0.40–0.60	0.52
Fine-Coarse Aggregate Ratio	1:1–3:1	3:2
Maximum-Size Coarse Aggregate	3/8"–1 1/2"	3/8 in.
* Fiber Content	0.5–2.5%	1.5%
Fiber Size	.016" × 1.0" round .010" × .022" × 1.0" Fibercon .016" × 0.75" Duoform	**

* Fibers are usually proportioned as a percentage of the volume of the cement, water, and aggregates. One percent of fibers corresponds to 132 lbs/cu yd.

** Fiber selection will be left to the user. Selection will depend on the distance of the job site from the various fiber suppliers.

Figure 2. Fiber balls resulting from poor techniques.

Conventional materials handling systems cannot handle fibers, and since bulk-handling facilities for fibers are not yet available, a considerable amount of manual labor is necessary to mix large batches of fibrous concrete, resulting in a slower batching operation. Manual handling of fibers requires all workmen to be equipped with protective gloves and goggles. For batch plant and ready-mix transit trucks, mixing methods in order of preference are:

Method 1. Blend fiber and aggregates prior to charging the mixer as might be done on a conveyer belt or aggregate chute. See Figure 3. Any clumps or nested groups of fibers should be broken up prior to charging the belt or chute to prevent the formation of fiber balls during concrete mixing. The flow or volume of aggregate on the belt or in the chute should be matched with the rate of fiber introduction to assure even distribution of the fibers thoughout the aggregates. By blending the fiber with the aggregates before they enter the mixer, the aggregates act as a fiber separator which prevents the fibers from nesting together to form fiber balls. Also the introduction of materials into the mixer such as cement, fly ash, water, and additives should be matched with the rate of flow of the fiber-aggregate mixture to assure a uniform mix.

Method 2. Blend fine and coarse aggregates in mixer. Then add fibers to the mixer, as shown in Figure 4, while the mixer rotates at its design mixing speed. This sequence serves to break clumps of fibers and distribute the fibers uniformly throughout the aggregates. Finally, add cement, fly ash, water, and additives simultaneously. This method is usually used when it is not possible to add the fiber in the batch plant system. The transit truck is removed from the batch plant after the aggregates are charged and returns to the plant for the cement, fly ash, water, and additives after the fiber is added.

Method 3. Add fiber at the weighing hopper along with the aggregates. Use standard mixing procedures throughout. Typically in this method there is access to the weighing hopper, and as the aggregates flow into the hopper a preweighed amount of fibers (the aggregate weight is adjusted to account for the fibers) are blended with the aggregates. Then the standard plant batching procedures are used.

Method 4. If extreme care is exercised, it is possible to add fiber to a ready-mix truck which contains a completed mix of plain concrete. This is accomplished by slowly sprinkling the fibers into the rotating drum after the concrete has been thoroughly mixed. The batch size should be limited to less than 40% of the rated capacity of the mixer and used with a lower fiber aspect ratio and percentage.

Quality Control. It is essential that all ingredients be carefully and accurately measured for each batch to insure uniform batches of fibrous concrete of proper proportions and consistency. Varying amounts of moisture nearly always present in the aggregate can cause trouble. The amount of free moisture introduced into the mixer with the aggregates can be determined and allowances made. Special care must be taken to remove all the wash water from the mixer before rebatching. The time required for thorough mixing of fibrous concrete is approximately the same as for ordinary concrete. When high cement factors are used, quicker setting times can be expected. High cement factors normally used for fibrous concrete will accelerate the setting time of the mix and should be accounted for during mixing and placing.

The only field procedure used to date to assess the uniformity of fiber distribution is the taking of random samples, 3 in. $\phi \times 6$ in. cylinders, of the fresh concrete and washing out the cement and collecting with a magnet the steel fiber in the sample. The fibrous concrete sample is weighed (W_c) and washed by dumping onto a screen with openings smaller than the fibers. To completely remove all material from the cylinder, the cylin-

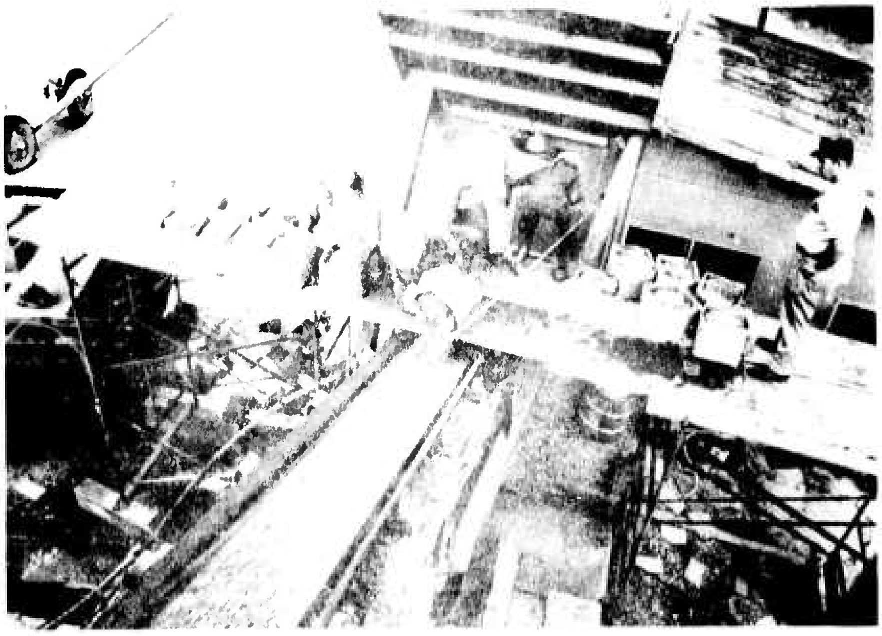

Figure 3. Blending fibers and aggregates on a conveyor belt.

Figure 4. Adding fibers directly to the mixer.

der is washed out over the screen and the dry, empty cylinder is weighed (W_c). The weight of the fibrous concrete (W_{fc}) is determined as follows:

$$W_{fc} = W_s - W_c$$

The cement is washed out by flushing water through the sample. After all cement is removed, the remaining material is oven dried and the steel fibers are collected with a cloth cover magnet and weighed (W_f). The percentage of fibers by weight (P_w) is calculated as follows:

$$P_w = (W_f/W_s) \times 100$$

This procedure provides a measure of fiber distribution consistency between batches.

Placing. A properly designed fibrous concrete mix can be placed using conventional techniques. Many specifications rely on the slump test as an indication of workability. The slump test can be used as a measure of workability when comparing different batches of fibrous concrete, but not when comparing fibrous concrete with plain concrete. It will take a slump of 4 or 5 in. in fibrous concrete to produce the same discharge and flow characteristics as a slump of 1 to 2 in. in plain concrete. But with vibration, the workability characteristic of a properly designed fibrous concrete mix is about the same as conventional plain concrete with equal slump.

Both internal and external vibration may be used but external vibration of the forms and external surfaces is preferred. When using an internal vibrator with a low slump mix, the paste material of the fibrous concrete tends to flow into the hole left by the vibrator, resulting in areas of poor fiber distribution. When used with a high-slump mix, an internal vibrator can produce segregation of fiber and aggregate. Both cases lead to zones of weakness in the fibrous concrete. Satisfactory internal vibration can be achieved by combining ordinary vibration procedures and a workable mix. Good concrete practice requires that concrete be placed as near its final position as possible; this is even more critical for fibrous concrete. Garden-type forks, hoes and rakes can be used for manual handling. In general, more vibration is required for consolidation of fibrous concrete. Figure 5 shows a vibrating screed that has proven very successful for slab work. Techniques for pumping fibrous concrete have not yet been developed, although preliminary work has indicated that pumping is feasible. Shotcreting of fibrous concrete is being practiced on a limited basis, with the only problem being the high percentage of fiber lost by rebound. Roadway and sidewalk paving machines have been used successfully with fibrous concrete (See Figures 6 and 7).

Finishing and Curing. Screeding can be accomplished

Figure 5. Vibrating screed.

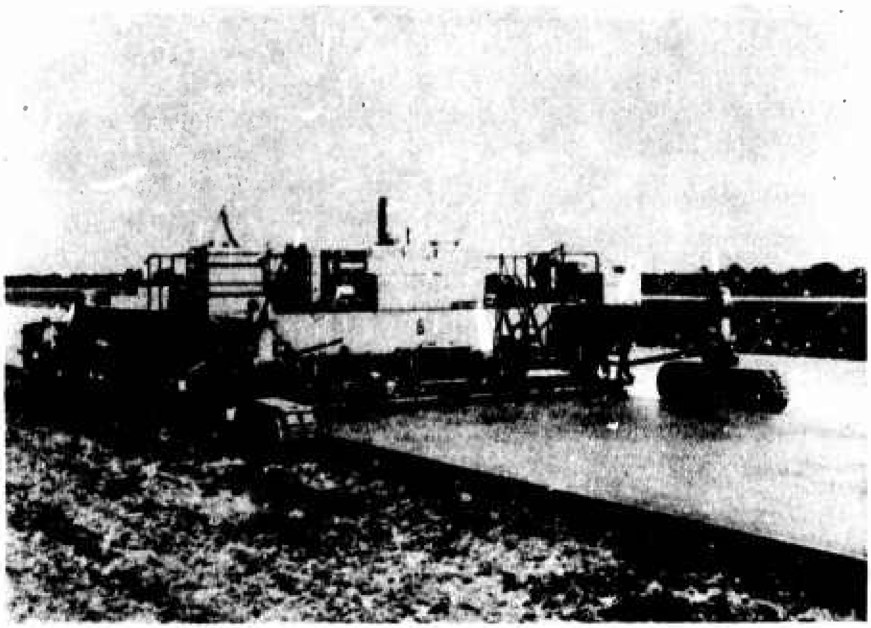

Figure 6. Road paver.

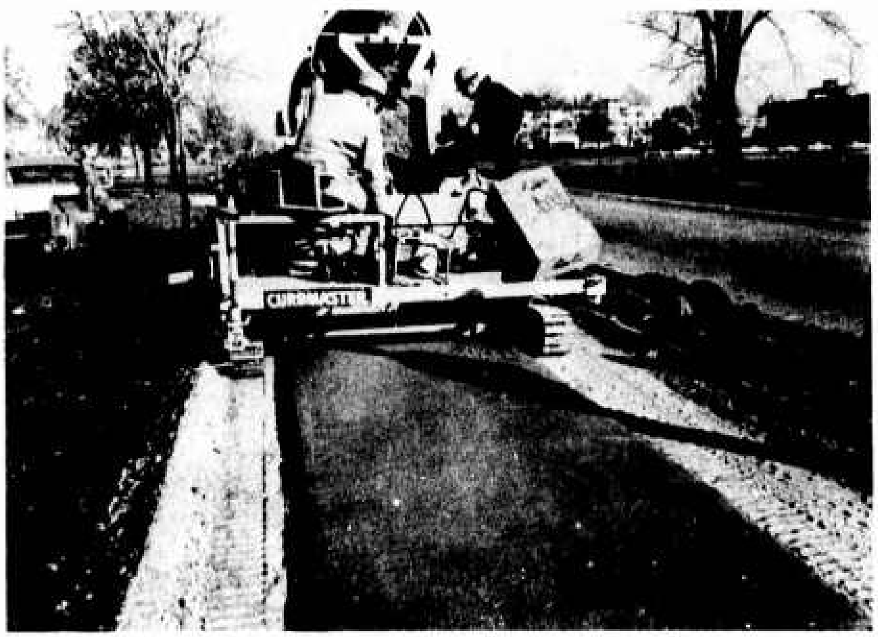

Figure 7. Sidewalk paver.

by the use of a wooden board, a portable vibrator mounted on boards, or by mechanical methods using full-scale conventional concrete unit such as a roadway or sidewalk paver. Conventional tools and techniques can be used for floating the fibrous concrete surface.

A scored surface can be produced by brooming with a stiff-hair brush, but should be delayed as long as possible to prevent the possibility of pulling fibers to the surface. Scoring by wet burlap drag is not recommended because the fibers can stick to the burlap and scar the surface of the concrete. Fibrous concrete should be cured and protected using the same methods and techniques as for conventional concrete.

3 APPLICATIONS, COST, AND ASSISTANCE

Applications. Fibrous concrete has applications analogous to those of general portland cement concretes. The potential user of fibrous concrete should weigh the higher cost of fibrous concrete against the benefits derived from improved characteristics and use of thinner sections of identical strength. These characteristics are listed in Table 2. Some proven applications are discussed below.

Fibrous concretes should generally be considered for all types of pavement applications, especially in areas where channelization of traffic and heavy loadings from traffic of pneumatic-tired vehicles, track-laying vehicles, and forklift trucks occur. Pavement slabs and overlays of fibrous concrete are thinner than those of conventional materials and are constructed with significantly fewer transverse joints. Fibrous concrete overlays of rigid and flexible pavements resist reflective cracking from the old base pavement. Fibrous concrete patches for rigid pavement repairs provide increased service life over conventional materials. Conventional patching techniques, as well as newly developed precast patching techniques, are suitable for fibrous concretes. Flexible pavement systems which now exist in areas subjected to deteriorating effects of POL (petroleum, oils, and lubricants) spillage and turn movements from heavy track vehicles can be overlaid with a very thin pavement of fibrous concrete.

When fibrous concrete is combined with conventional reinforcement, the composite material becomes an excellent barrier wall which provides a very high energy-absorbing capability with superior spall resistant qualities. Security storage vaults and blast resistant shelters are excellent applications of fibrous conventional reinforced concretes.

Areas exposed to severe abrasion and erosion such as docks and warehouse floors subjected to hard solid rubber and steel-tired vehicles, flip-lip energy disaparators at water outlets of dams, and concrete units for jetty armor are excellent potential uses of fibrous concrete.

Fibrous concrete might be used for refractive products in conditions where large thermal gradients exist, such as linings in cement kilns and open-hearth furnace doors. Stainless steel fibers and refractive cements resist the deteriorating action of the high temperatures; the fibers prevent catastrophic failure by restricting crack propagation.

Areas that require increased fatigue, impact, and crack control, e.g., bridge decks, cyclic temperature environment room floors, and concrete units for jetty armor are proving applications of fibrous concretes. Concrete units for jetty armor, for example, are subjected to several types of loading actions and can fully utilize many of the excellent characteristics of fibrous concrete. The loading caused by waves from storms can be of such magnitude to produce cracking, abrasion, and erosion of the conventional, reinforced concrete unit thus allowing chloride corrosion of the reinforcement and leading to complete breakage of the units. Breakage of the unit will affect the stability of the interlocking system of units. Full scale tests of units constructed of a dense fibrous concrete (no conventional reinforcement) has developed a first crack strength increase of 100% over the conventional reinforced units.

Costs. The present cost of steel fiber is 18¢ per pound. Shipping cost depends on the distance involved and is typically 1 to 3¢ per pound of fiber. Fibrous concrete batching costs may be slightly in excess of those for ordinary plain concrete due to the lack of bulk handling equipment for the fibers. The increased cost of fiber batching is typically 1/2¢ per pound of fiber. Therefore, the average cost of the steel fiber in the mixer is 20 1/2¢ per pound of fiber. For an average fibrous concrete mix of 195 lbs of steel fiber per cu yd of concrete (approximately 1.5% by volume), the fiber cost in the mixer would be $40.00 per cu yd of concrete. A typical estimate for the in-place cost of a plain concrete slab would be $40.00 per cu yd of concrete. Since fibrous concrete is plain concrete with a random

dispersion of steel fibers, the in-place cost of a fibrous concrete slab would be the fiber cost in the concrete mixer plus the plain concrete cost which would make the fibrous concrete cost $80.00 per cu yd. The economic justification for the use of fibrous concrete can only result from applications that fully utilize the overall superior response of the material. For example, the use of fibrous concrete for pavement applications will result in a slab or overlay approximately one-half as thick as the plain concrete slab, but with a greater life expectancy than the thicker plain concrete slab. Based on this thickness reduction and the above cost estimate, an 8 in.-thick plain concrete pavement or a 4 in.-thick fibrous concrete pavement would cost $8.90 per sq yd of surface area. The initial costs may be the same, but the fibrous concrete pavement would be expected to provide a longer service life with less maintenance.

Technical Assistance and Monitoring. CERL is prepared to provide technical assistance to any Corps of Engineers Office that desires to use fibrous concrete. This includes assistance in considering applications, cost analysis, engineering design, preparing specifications, concrete mix design, fiber batching, and application construction. For these services, CERL requests the privilege of monitoring the installation for performance.

For assistance, contact:

Department of the Army
Construction Engineering Research Laboratory
Attn: Mr. E. A. Lotz
Construction Materials Branch
P.O. Box 4005
Champaign, IL 61820

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